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PROCESS FOR REMOVING POLLUTANTS FROM AQUEOUS STREAMS

FIELD OF THE INVENTION

[0001] This invention relates to a process for removing pollutants from an aqueous stream using a composite which is a mixture of a microporous cation exchange composition and an anion exchange composition. Cation exchange compositions are zirconium metallates and titanium metallates, while examples of anion exchange compositions are hydrous zirconium oxide, zirconia, etc.

BACKGROUND OF THE INVENTION

[0002] It is well known that ammonia or ammonium cation is a serious pollutant in water. At high concentrations ammonium ions are toxic to aquatic life. Ammonium ions in stream, lakes, etc. are converted to nitrites which are also toxic to aquatic life and finally the nitrites are converted to nitrates which are not as toxic as ammonium ions or nitrites, but can contribute to eutrophication. Eutrophication is defined as the process by which a body of water becomes enriched in dissolved nutrients (nitrates, phosphates and ammonium ions) that stimulate the growth of aquatic plant life, e.g. algae blooms, usually resulting in the depletion of dissolved oxygen. In order to minimize these detrimental effects, government regulations often limit the concentrations of nitrogen (ammonium ions and nitrates) and phosphorus (phosphates).

[0003] There are several advantages to removing ammonium ions from waste water. Reuse of municipal waste water requires a 90-95% reduction in the ammonium ion concentration typically found in waste water. In the past this treatment has been

prohibitively costly. Chlorine disinfection of water is also affected since ammonium ions react with chlorine to form chloramines which, while still bactericides are slower acting and less effective. Finally, ammonium cations are corrosive to certain metals and other materials.

5 **[0004]** Some municipal wastewater treatment plants have used the zeolite clinoptilolite to remove ammonium ions from wastewater. J.D. Sherman and R.J. Ross in "Proceedings of the Fifth International Conference on Zeolites", L.V.C. Rees, editor, Heyden Press, pp. 823-831 (1980), disclose the use of zeolites F and W for removing ammonium ions from a synthetic wastewater. In U.S. 4,344,851 B1 it is
10 disclosed that phillipsite type zeolites can remove ammonium ions in the presence of calcium ions.

[0005] In contrast to these zeolites, applicants have developed a composite which contains an anion and a cation exchanger. The cation exchanger is a microporous composition having an empirical formula on an anhydrous basis of:



or



where A is an exchangeable cation selected from the group consisting of potassium ion, sodium ion, rubidium ion, cesium ion, calcium ion, magnesium ion, hydronium
20 ion or mixtures thereof, M is at least one framework metal selected from the group consisting of hafnium (4+), tin, (4+), niobium (5+), titanium (4+), cerium (4+), germanium (4+), praseodymium (4+), and terbium (4+), except that M is not titanium in formula (II), "p" has a value from about 1 to about 20, "x" has a value from zero to less than 1, "n" has a value from 0 to about 12, "y" has a value from 0 to about 12,
25 "m" has a value from about 3 to about 36 and $1 \leq n + y \leq 12$. The germanium can substitute for the silicon, zirconium/titanium or combinations thereof. Examples of the anionic exchange composition are hydrous zirconium oxide and zirconia.

SUMMARY OF THE INVENTION

[0006] This invention relates to a process for removing pollutants from aqueous streams. Accordingly, one embodiment of the invention involves contacting the aqueous stream with a shaped ion exchange composite at ion exchange conditions thereby removing at least some of the pollutants, the composite comprising a mixture of a microporous cation exchange composition and an anion exchange composition, where the cation exchange composition is selected from the group consisting of zirconium metallate, titanium metallate and mixtures thereof, the metallates respectively having an empirical formula on an anhydrous basis of:

10



or



15

where A is an exchangeable cation selected from the group consisting of potassium ion, sodium ion, calcium ion, magnesium ion and mixtures thereof, M is at least one framework metal selected from the group consisting of hafnium (4+), tin (4+), niobium (5+), titanium (4+), cerium (4+), germanium (4+), praseodymium (4+), and terbium (4+), except that M is not titanium in formula (II), "p" has a value from about 1 to about 20, "x" has a value from zero to less than 1, "n" has a value from 0 to about 12, "y" has a value from 0 to about 12, "m" has a value from about 3 to about 36 and $1 \leq n + y \leq 12$, and the anion exchange composition is selected from the group consisting of hydrous zirconium oxide, zirconia, alumina, titania, hydrous titanium oxide, layered double hydroxides, single phase metal oxide solid solutions, magnesium hydroxide, calcium hydroxide, silica, amorphous mixed metal oxides, basic clays and mixtures thereof.

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DESCRIPTION OF THE FIGURE

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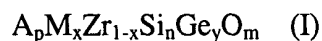
[0007] The figure presents a plot of percent ammonium ion present in the effluent versus bed volume for a composition of the invention and a reference zeolite.

DETAILED DESCRIPTION OF THE INVENTION

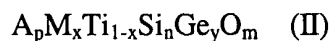
[0008] Applicants have developed a process for removing pollutants from aqueous streams using an ion exchange composite. One essential element of applicants' process is the use of a composite which comprises a microporous cation exchange composition and an anion exchange composition. Cation exchange compositions are well known in the art and are defined as compositions which contain cations that can be exchanged with other cations without altering the structure of the composition. Zeolites and non-zeolitic molecular sieves are examples of cation exchangers.

[0009] Applicants have determined that microporous compositions identified as zirconium metallate and titanium metallate compositions have a large capacity for ammonium cations. The microporous compositions are described in U.S. 5,891,417 B1 and U.S. 6,099,737 B1 both of which are incorporated by reference.

[0010] These compositions are further identified by their empirical formulas (on an anhydrous basis) which respectively are:



or



In the case of formula I, the composition has a microporous framework structure composed of ZrO_3 octahedral units and at least one of SiO_2 tetrahedral units and GeO_2 tetrahedral units. In the case of formula II, the microporous framework structure is composed of TiO_3 octahedral units and at least one of SiO_2 tetrahedral units and GeO_2 tetrahedral units.

[0011] In both formulas I and II, A is an exchangeable cation selected from the group consisting of potassium ion, sodium ion, rubidium ion, cesium ion, calcium ion, magnesium ion, hydronium ion or mixtures thereof, M is at least one framework metal selected from the group consisting of hafnium (4+), tin (4+), niobium (5+), titanium (4+), cerium (4+), germanium (4+), praseodymium (4+), and terbium (4+), "p" has a

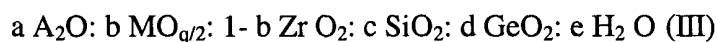
value from about 1 to about 20, "x" has a value from zero to less than 1, "n" has a value from 0 to about 12, "y" has a value from 0 to about 12, "m" has a value from about 3 to about 36 and the sum of $n + y$ has a value from about 1 to about 12. That is $1 \leq n + y \leq 12$. In equation (II) M is, of course, not titanium. The M metals which can be inserted into the framework in place of zirconium will be present as MO_3 octahedral units and thus it is a requirement that they are capable of being octahedrally coordinated. The germanium can be inserted into the framework in place of silicon and will be present as MO_2 tetrahedral units. Additionally, germanium can be inserted into the framework as a MO_3 octahedral unit replacing some of the zirconium in formula (I) or some of the titanium in formula (II). That is, germanium can replace some or all of the silicon, some of the zirconium in formula (I), some of the titanium in formula (II) or both silicon and zirconium or both silicon and titanium.

[0012] The zirconium metallates are prepared by a hydrothermal crystallization of a reaction mixture prepared by combining a reactive source of zirconium, silicon and/or germanium, optionally one or more M metal, at least one alkali metal and water. The alkali metal acts as a templating agent. Any zirconium compound, which can be hydrolyzed to zirconium oxide or zirconium hydroxide, can be used. Specific examples of these compounds include zirconium alkoxide, e.g., zirconium n-propoxide, zirconium hydroxide, zirconium acetate, zirconium oxychloride, zirconium chloride, zirconium phosphate and zirconium oxynitrate. The sources of silica include colloidal silica, fumed silica and sodium silicate. The sources of germanium include germanium oxide, germanium alkoxides and germanium tetrachloride. Alkali sources include potassium hydroxide, sodium hydroxide, rubidium hydroxide, cesium hydroxide, sodium carbonate, potassium carbonate, rubidium carbonate, cesium carbonate, sodium halide, potassium halide, rubidium halide, cesium halide, sodium ethylenediamine tetraacetic acid (EDTA), potassium EDTA, rubidium EDTA, and cesium EDTA. The M metals sources include the M metal oxides, alkoxides, halide salts, acetate salts, nitrate salts and sulfate salts. Specific examples of the M metal sources include, but are not limited to titanium

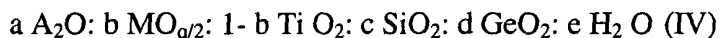
alkoxides, titanium tetrachloride, titanium trichloride, titanium dioxide, tin tetrachloride, tin isopropoxide, niobium isopropoxide, hydrous niobium oxide, hafnium isopropoxide, hafnium chloride, hafnium oxychloride, cerium chloride, cerium oxide and cerium sulfate.

- 5 **[0013]** The titanium metallates are prepared in an analogous manner to the zirconium metallates. Thus, the sources of silicon, germanium, M metal and alkali metal are as enumerated above. The titanium source is also as enumerated above, namely titanium alkoxides, titanium tetrachloride, titanium trichloride and titanium dioxide. A preferred titanium source is titanium alkoxides with specific examples being titanium
- 10 isopropoxide, titanium ethoxide and titanium butoxide.

[0014] Generally, the hydrothermal process used to prepare the zirconium metallate or titanium metallate ion exchange compositions involves forming a reaction mixture which in terms of molar ratios of the oxides is expressed by the formulae:



15 and



where "a" has a value from about 0.25 to about 40, "b" has a value from 0 to about 1, "q" is the valence of M, "c" has a value from about 0.5 to about 30, "d" has a value from 0 to about 30 and "e" has a value of 10 to about 3000. The reaction mixture is prepared

20 by mixing the desired sources of zirconium, silicon and optionally germanium, alkali metal and optional M metal in any order to give the desired mixture. It is also necessary that the mixture have a basic pH and preferably a pH of at least 8. The basicity of the mixture is controlled by adding excess alkali hydroxide and/or basic compounds of the other constituents of the mixture. Having formed the reaction mixture it is next reacted at

25 a temperature of about 100°C to about 250°C for a period of about 1 to about 30 days in a sealed reaction vessel under autogenous pressure. After the allotted time, the mixture is

filtered to isolate the solid product which is washed with deionized water and dried in air.

[0015] As stated the microporous compositions have a framework structure of octahedral ZrO_3 units, at least one of tetrahedral SiO_2 units and tetrahedral GeO_2 units and optionally octahedral MO_3 units. This framework results in a microporous structure having an intracrystalline pore system with uniform pore diameters, i.e., the pore sizes are crystallographically regular. The diameter of the pores can vary considerably from about 3 Å and larger.

[0016] As synthesized, the microporous compositions will contain some of the alkali metal templating agent in the pores. These metals are described as exchangeable cations, meaning that they can be exchanged with other (secondary) A' cations. Generally, the A exchangeable cations can be exchanged with A' cations selected from other alkali metal cations (K^+ , Na^+ , Rb^+ , Cs^+), alkaline earth cations (Mg^{2+} , Ca^{2+} , Sr^{2+} , Ba^{2+}), hydronium ion or mixtures thereof. It is understood that the A' cation is different from the A cation. The methods used to exchange one cation for another are well known in the art and involve contacting the microporous compositions with a solution containing the desired cation (at molar excess) at exchange conditions. Exchange conditions include a temperature of about 25°C to about 100°C and a time of about 20 minutes to about 50 hours. The particular cation (or mixture thereof) which is present in the final product will depend on the particular use and the specific composition being used. One specific embodiment is a cation exchange composition where the A' cation is a mixture of Na^+ , Ca^{+2} and H^+ ions.

[0017] These cation exchange compositions have been designated UZSi-n (see the '417 and '737 patents) where "n" is an integer which denotes a specific crystalline phase. Specific phases which are useful in the present invention include but are not limited to UZSi-1, UZSi-9 and UZSi-11.

[0018] Another essential component of the present invention is an anion exchange composition. Non-limiting examples of these anion exchange compositions are

hydrous zirconium oxide, zirconia, alumina, titania, hydrous titanium oxide, layered double hydroxides (LDH), single phase metal oxide solids solutions (MOSS), magnesium hydroxide, calcium hydroxide, silica, amorphous mixed metal oxides, and basic clays. The preparation of these anion exchange compositions is well known in the art and some are commercially available. By single phase metal oxide solid solutions is meant mixtures of metal oxides which form a solid solution, i.e. one oxide "dissolved" in the other oxide but which have only one phase as shown by x-ray diffraction. One example of a MOSS is ceria/zirconia with varying ratios of Ce/Zr. Layered double hydroxides are compositions comprised of octahedral layers, i.e. the metal cations are octahedrally surrounded by hydroxyl groups. These octahedra share edges to form infinite sheets. Interstitial anions such as carbonate are present to balance the positive charge in the octahedral layers. One example of a LDH is hydroxalcalite. U.S. 5,232,887 B1 and references cited therein, all of which incorporated by reference, present details on LDH including preparation procedures. Amorphous mixed metal oxides are chemical mixtures (not physical mixtures) of oxides which are x-ray amorphous. An example of these amorphous materials is amorphous silica-alumina, which is described in U.S. 3,909,450 B1, U.S. 3,274,124 B1 and U.S. 4,988,659 B1 all of which are incorporated by reference. Finally, examples of clays (without limitation) include halloysite, bentonite, montmorillonite, etc.

[0019] The cation and anion exchange compositions are next combined and formed into various shapes by means well known in the art. Non-limiting examples of these various shapes include pills, extrudates, spheres, pellets and irregularly shaped particles. Although the microporous compositions can be formed into shaped articles without using a binder, it is preferred to use a binder. The binders which can be used are well known and include alumina, silica, amorphous silica/alumina, hydrous zirconium oxide, zirconia, zirconium phosphate, alumina, aluminum phosphate, titania, titanium phosphate, hydrous titanium oxide, layered double hydroxides, magnesium hydroxide, calcium hydroxide, silica, basic clays and mixtures thereof. Again the process of preparing shaped articles using a binder is well known in the art.

For example, the desired binder can be peptized with an acid such as nitric acid or hydrochloric acid and then combined with the cation and anion exchange compositions, formed into the desired shape and finally calcined to form a shaped article. Since the binder materials include many of the anion exchange compositions, one can use the same binder as the anion exchanger or a binder which is different from the anion exchanger. If the binder is the same as the anion exchanger, one can peptize the entire amount of anion exchanger and then convert it to the oxide or use a portion in the oxide form and a portion which is peptized and used as a binder.

[0020] A particular procedure which can be used when the binder is hydrous zirconium oxide or hydrous titanium oxide is described in U.S. 6,099,737 B1 which is incorporated by reference. This procedure is described here for completeness. The process uses a binder precursor which when heated as described below will be converted to a hydroxy zirconium or titanium oxide binder. The binder precursors are metal compounds which can form a gel by changing pH. Examples of the binder precursors which can be used, include but are not limited to zirconium tetrapropoxide, zirconium acetate solution, zirconyl hydroxychloride, zirconyl oxychloride, zirconyl orthosulfate, zirconyl oxynitrate, and the titanium analogs of the above named compounds.

[0021] Generally the binder precursor is conveniently mixed with water, to which the desired cation and anion exchange compositions are added or vice versa to form a mixture. The amount of precursor in the mixture can vary considerably, but is generally the amount necessary to give from about 10 to about 50 wt.% of hydroxy metal oxide in the finished shaped article. The resultant mixture is homogeneously mixed by means well know in the art such as mulling, kneading, shearing, stirring, etc. Water is usually added to the mixture before or during mixing to obtain the appropriate consistency required for the desired forming means. The amount of water which is added will also determine the type of mixing means to be used.

[0022] Since the binder precursor undergoes gelation during preparation of the shaped article, it is important to control the gelation rate of the precursor. Failure to control the gelation rate can result in an inhomogeneous mixture of the binder and cation plus anion exchange compositions or result in the binder/composition mixture being turned into an unworkable mass. For example, a large or drastic shift in pH can occur when very basic cation plus anion exchange compositions are mixed with a very acidic binder precursor. Examples of these very basic compositions are alkali silicotitanates, or alkali metallogermanates, while clays are only slightly basic.

[0023] If it is found that the cation plus anion exchange compositions are too basic and cause premature gelation, they can be treated to reduce the basicity. This can be done by treating the mixed composition with an acid solution such as nitric acid, hydrochloric acid, etc., and used directly in the formulation or, alternatively, followed by filtration and washing with water. This procedure is carried out until the resultant acid washed cation plus anion exchange composition when mixed with the binder precursor gives a homogeneous and workable mixture or slurry.

[0024] An alternative way to prepare a mixture of the binder precursor and cation plus anion exchange composition is to first gel the precursor and then mix it with the composition. One convenient manner of gelling the binder precursor is by preparing an aqueous solution of base such as sodium hydroxide, potassium hydroxide, etc. and adding the binder precursor to it. The resultant slurry is filtered, the solid washed and then mixed with the desired cation plus anion exchange compositions. When preparing an article using the gelled binder precursor and a very basic cation plus anion exchange composition, it is not necessary to treat the cation plus anion exchange composition with an acid, although it is preferred to do so.

[0025] Having obtained a homogeneous mixture, it is now formed into a desired shape by forming means well known in the art. These forming means include extrusion, spray drying, oil dropping, conical screw mixing, etc. Extrusion means include screw extruders and extrusion presses. As mentioned above, the forming

means will determine how much water, if any, is added to the mixture. Thus if extrusion is used, then the mixture should be in the form of a dough, whereas if spray drying or oil dropping is used, then enough water needs to be present in order to form a slurry. Note that these forming steps can be used for any binder.

5 **[0026]** Having formed the mixture into a desired article, it is next heated at temperatures of about 85°C to about 120°C. Heating at these low temperatures sets the binder but does not convert it to the oxide. Therefore, one obtains a shaped article comprising a cation and anion exchange compositions and a hydroxy metal oxide binder. By a hydroxy metal oxide is meant an oxide having the empirical formula
10 $MO_2 \cdot xH_2O$, where x ranges from about 2 to about 4 and M is zirconium or titanium. They hydroxy metal oxide is x-ray amorphous or poorly crystalline.

15 **[0027]** Although the preferred embodiment is to have shaped articles containing both an anion and a cation exchange composition, the two exchange compositions can be present as separate articles (prepared as above) which can then be physically mixed or be in separate beds.

20 **[0028]** Turning now to the process itself, the waste stream to be treated is contacted with the ion exchange composite thereby removing at least some of the pollutants from the stream and absorbing them onto the composite. The contacting can be done either in a batch or continuous mode. If a batch mode is used, the ion exchange composite is placed in an appropriate container and the stream to be treated mixed therewith. Contacting is carried out for a time of about 1 minute to about 24 hours and at a temperature of about 25°C to about 90°C. In a continuous mode, the molecular sieve is placed in a column and the stream to be treated is flowed through it, usually downflow, until ammonium ions and/or phosphate ions are detected in the
25 effluent of the column. Once the column is saturated with pollutant ions, the ion exchange composite can either be disposed of or can be regenerated by well known means. The stream is flowed through the column at a rate of about 2 to about 20 bed volumes/hr (BV/hr). The temperature at which the contacting is carried out is the

same as in the batch process which is from about 25°C to about 90°C. Although the process is usually operated at atmospheric pressures, super-atmospheric pressures up to about 10 atm can be used.

[0029] The following examples are presented to more fully illustrate the invention. It is to be understood that the examples are only by way of illustration and are not intended as an undue limitation on the broad scope of the invention as set forth in the appended claims.

EXAMPLE 1

[0030] In a stainless steel container, 2209 g KOH was dissolved in 7654 g of deionized water. The resulting solution was stirred and allowed to cool to below 35°C. To the stirring KOH solution there were added 2057 g of Ludox AS-40. After additional stirring, 2083 g zirconium acetate was added and the gel was pumped to a five gallon reactor equipped with an anchor agitator. The reactor was heated over three hours to 200°C and held there for 36 hours at which point the reactor was cooled to room temperature. The resulting product was isolated by vacuum filtration, washed with 2 liters of deionized water and then dried in air overnight. Then x-ray powder diffraction of the sample showed it to be UZSi-1. Elemental analysis by ICP gave on a volatile free basis 21.0 wt% Zr, 20.5 wt% K, 21.5 wt% Si, LOI 16.9 wt% ($K_{2.28}ZrSi_{3.38}O_{9.9} \cdot 4.89H_2O$).

[0031] A slurry of UZSi-1 in water was prepared by mixing 385 g of the UZSi-1 powder from above and 400 g of water and milling for 40 minutes. A 42 wt% hexamethylenetetraamine (HMT) solution chilled to about 10°C was added with stirring to a similarly chilled solution of urea (26 g) dissolved in zirconyl acetate (279 g, 28.6% ZrO_2 basis). The UZSi-1 slurry was now added to the chilled mixture and vigorously stirred. The resultant slurry was dropped into an oil tower maintained at 100°C. Spheres measuring about 0.2 to 0.4 mm in diameter were removed from the bottom of the tower, aged overnight at 95°C in oil, and treated by circulation a 2N KOH solution through the spheres for 24 hours. At this point, the solution was

EXAMPLE 4

[0035] A solution was prepared by mixing 4150g of sodium silicate, 484g of sodium hydroxide and 1909g H₂O. After several minutes of vigorous stirring 2458g zirconium acetate solution (22.1 wt.% ZrO₂) was added. This was stirred for an additional 15 minutes and the resulting gel was transferred to a stainless steel reactor and stirred for 72 hours at 200°C. The reactor was cooled to room temperature and the mixture was vacuum filtered to isolate solids which were washed with deionized water and dried in air. The solid reaction product was analyzed and found to contain 16.72 wt.% Na₂O, 51.98 wt.% SiO₂, 30.93 wt.% ZrO₂, LOI 10.8 wt.%, which gives a formula of Na_{2.15}ZrSi_{3.45}O_{9.97}•2.68H₂O. This product was identified as UZSi-9 by powder XRD and labeled sample B.

EXAMPLE 5

[0036] To a vessel there were mixed 458g of sample B and 355g of water to provide a slurry with a pH of about 13. Glacial acetic acid was added slowly to reach a final slurry pH of about 6.

[0037] The above slurry was added to a container, which was chilled to about 10 to 15°C. To this slurry there were added 350g of zirconyl acetate which had been chilled to 10 to 15°C and the resultant slurry was stirred vigorously. Next the slurry was spray dried to provide 20 to 50 micron diameter particles.

EXAMPLE 6

[0038] A mixture of 70g of zirconyl nitrate and 13g of water was added to a container, to which there were added 29ml of a 20wt.% sodium hydroxide solution to give a soft gel. The gel along with 89g of sample B were added to a muller and the mixture mulled for 30 minutes. Next, 10g of water and 2g of glycerin were added, the mixture mulled for an additional 10 minutes and then extruded using a piston extruder. The extrudates were dried at room temperature overnight and then calcined at 200°C

for two hours. Finally, the extrudates were crushed to give particles of about 250 to about 420 microns in diameter. This sample was identified as sample H-1.

EXAMPLE 7

5 [0039] One half of the H-1 sample was further crushed to provide a powder comprised of particles of less than 50 microns in diameter. This sample was identified as sample H-2.

EXAMPLE 8

10 [0040] Extrudates were prepared by first mulling 276g of sample B. To the muller, 87g of magnesium hydroxide ($Mg(OH)_2$) were added and the resultant mixture kneaded for 10 minutes. Next, 373g of water were added to increase the extrudability of the dough and mulling was continued for an additional 30 minutes. The mixture was extruded on a piston extruder using a 1.78 mm die plate. The resultant extrudates were dried overnight under ambient conditions and then heated at 200°C for two hours. The dried extrudates were next crushed to give particles of about 250 to about 15 600 microns in diameter. This sample was identified as sample M.

EXAMPLE 9

20 [0041] Samples B, H-1, H-2 and M were tested for removal of ammonium and phosphate ions using the following procedure. A test solution was prepared by mixing 28.6ml of a dialysate concentrate with 971ml of deionized water, 2.675g of ammonium chloride (NH_4Cl) and 0.446g of monobasic monhydrate sodium phosphate ($NaH_2PO_4 \cdot H_2O$). The final composition of the dialysate test solution is shown in Table 1.

Table 1
Dialysate Test Solution Composition

Element	wt. %
Na	0.314
Ca	0.0049
K	0
Mg	0.0018
NH ₄	0.105
P	0.0107

[0042] Into a 25ml vial, there were added 200mg of the sample to be tested, to which there were added 10ml of the above test dialysis solution. The vial was placed in an upright shaker and agitated at room temperature for 24 hours. The mixture was then filtered and the filtrate analyzed for NH₄⁺ and phosphorous. The results for these samples are presented in Table 2.

Table 2
Removal of Dialysate Components by Various Compositions

Sample ID	Amount of Component Removal (%)	
	NH ₄	Phosphorus
A	91.5	5.6
H-1	86.7	100
H-2	87.6	100
M	82.9	100
ZrPO ₄ *	61.0	0 ¹
ZrO ₂ *	6.7	100

* Obtained from a commercial Redy™ cartridge
1 product analysis similar to feed

The results in Table 2 show that the composites of the invention are able to remove both ammonium and phosphorous ions better than conventional materials. Note that

the amount of UZSi-9 in samples H-1, H-2 and M are less than the amount (weight) of ZrPO_4 or the pure UZSi-9 (sample A). Additionally, the amount of ZrO_2 in the H-1 or H-2 samples is less than in the pure ZrO_2 . Surprisingly, samples H-1 and H-2 have substantially similar performance to the pure components while using smaller amounts of materials.

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